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WAIT! HOW WE CONTROL OUR THOUGHTS AND ACTIONS AS WE AGE

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YOUNG REVIEWERS:

AKSHARA
AGE: 13

MAYA
AGE: 15

Have you ever sat next to someone in class who cannot stop talking? You would like to focus on your teacher, but you cannot avoid listening to your talkative classmate. This is what inhibition is useful for! Inhibition is the ability to ignore, suppress, and resist irrelevant information coming from the environment or from our own minds. Inhibition is more difficult for young kids, is optimal in young adults, and becomes more problematic as we age. How does inhibition work? Why does inhibition change as we age? Can we train inhibition? In this article, we will try to answer these questions.

WHAT IS INHIBITION?

Imagine you are in your classroom and want to pay attention to your teacher. In the meantime, you hear two of your friends whispering, and another one is typing on his phone under the table next to you. To focus on your teacher's words, you need to mentally suppress the noise produced by your classmates. This is called **inhibition**. Inhibition

INHIBITION

The brain's ability to control unwanted behavior, emotions, and thoughts by stopping them or by preventing them from occurring.

ACCESS FUNCTION

A function of inhibition that prevents irrelevant information from accessing our awareness, only letting in the important information that we need.

DELETION FUNCTION

A function of inhibition that removes potentially distracting information that succeeded in accessing the mind, or that removes information that is not important anymore.

RESTRAINT FUNCTION

A function of inhibition that reduces strong and inappropriate responses, thoughts, or behaviors.

is the ability to ignore, suppress, and resist irrelevant information coming from your environment or from your own mind [1]. It allows you to think, learn, reason, remember, and solve problems without being overwhelmed by too much information. It is also very important for controlling your body and emotions. You can read this Frontiers for Young Minds article to get more information about how we inhibit physical actions, such as stopping yourself from crossing a road when you hear a truck coming.

In our lab, we are interested in the role of inhibition in memorizing and retrieving information accurately. Inhibition allows us to filter the things we are thinking about or that we are retrieving from memory. This filter has three functions (Figure 1). The first one is the **access function**: inhibition can allow information to reach our awareness or prevent it from reaching our awareness. Access helps us to focus on and memorize the most relevant information while ignoring the many less important bits. The second is the **deletion function**. Deletion removes potentially distracting information that comes into our minds or information that is not important anymore. If you think about a lunch you had last week at school, you would probably remember the friends sitting at your table, and maybe what you ate. But you would probably not remember the color of your chair (unless this information is very important to you). The third function of inhibition is the **restraint function**. Restraint allows us to reduce strong but inappropriate responses, thoughts, or behaviors, such as yelling when you are playing video games if your siblings are asleep.

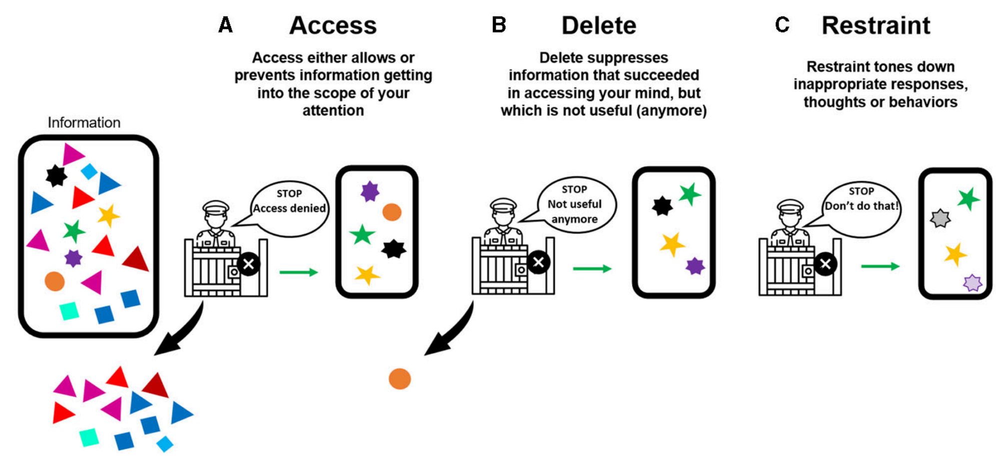

Figure 1

Figure 1

Inhibition has three functions: access, deletion, and restraint. Inhibition acts like a gatekeeper controlling access to an event. **(A)** Initially, the gatekeeper can deny access to the event if a person does not own the ticket to enter. This is the access function of inhibition. **(B)** During the event, the gatekeeper can kick out anyone whose behavior is not appropriate anymore. This illustrates the deletion function. **(C)** The gatekeeper can warn anyone showing excessive behavior during the event. This is the restraint function.

HOW DO WE MEASURE INHIBITION?

There are many tasks that we use in the lab to measure inhibition. One of them is called the Stroop test (Figure 2A). In this test, people must name the font color of color words, like blue, red, and green. They have to inhibit an automatic response when asked to name the color of the word. When seeing the word "blue," the brain automatically reads the word "blue" instead of answering "red." This is called the Stroop effect. Another task to measure inhibition is called the Simon task (Figure 2B). In this task, people see either a yellow or a green dot on the left or on the right side of the screen. The left button has to be pressed for the yellow dot, and the right button has to be pressed for the green dot. People respond slower and less accurately if the location of the dot on the screen and the location of the response button do not match: that is when the dots appear on right-left locations of the screen opposite to the requested left-right button response; the location on the screen requires inhibition. This is called the Simon effect. The last task we will describe is called a verbal inhibition task (Figure 2C). In this task, people have to complete sentences. In the easy part, sentences have to be completed with a meaningful ending. In the difficult part, sentences have to be completed with a non-sense ending. Participants tend to have difficulties ending sentences with non-sense words if asked to; instead, they want to produce the word that would usually complete the sentence.

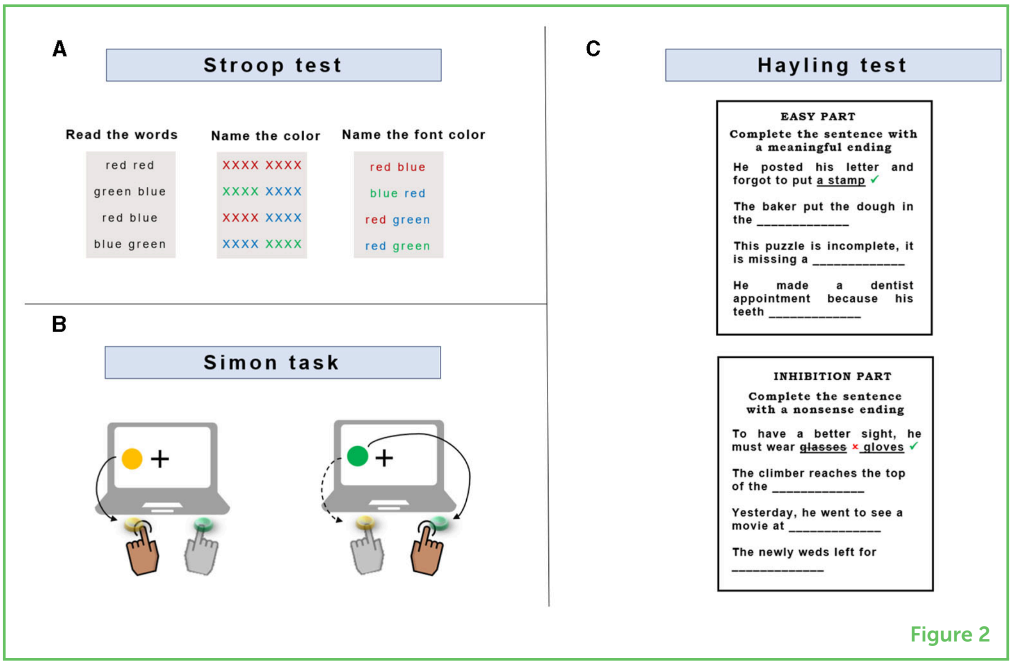

Figure 2

Several laboratory tests can be used to measure inhibition. **(A)** In the Stroop test, people have to inhibit an automatic response when asked to name the ink color of the word. **(B)** In the Simon test, must inhibit the incongruency between the dot and the response button locations. **(C)** The Hayling test is an example of a verbal inhibition task, in which people must inhibit meaningful endings to complete sentences correctly.

Another way to study the brain is to look at it using brain imaging techniques, such as **magnetic resonance imaging** (MRI; to learn more about MRI, see this Frontiers for Young Minds article). MRI studies have shown that, during tasks like the Stroop test that require access inhibition, a part of the brain called the **prefrontal cortex** is extra active. Scientists think that this increased activity might reflect the work of the brain to suppress irrelevant information, allowing us to focus on what is important.

MAGNETIC RESONANCE IMAGING (MRI)

An MRI scanner uses a strong magnet to take pictures of the brain. It helps scientists learn which areas of the brain are active when you engage in different activities.

HOW INHIBITION CHANGES WITH AGE

PREFRONTAL CORTEX

Part of the brain's frontal lobe; the brain area most developed in humans compared to our primate cousins. It supports the regulation of complex mental, emotional, and behavioral functions.

Typically, inhibition emerges around 3–4 years old, becomes more efficient during childhood and adolescence, and is fully developed in early adulthood. But what happens at the other end of human development? As people get older, inhibition tends to decrease, potentially affecting behaviors in everyday life [2]. In the lab, we can compare young adults (18–40) and older adults (60–80) on inhibition tasks like those in Figure 2. Older adults tend to have more difficulties performing these tasks [3]. For example, the Stroop effects can be increased, indicating difficulties with the deletion function. The Simon effect can also be more pronounced, showing a decrease in the restraint function. Finally, older adults may have more difficulties preventing irrelevant information from entering their minds. For example, they may need more time to read a text if irrelevant words are added. This indicates a decrease in the access function. In daily life, problems with inhibition can affect very simple behaviors. For example, we may buy apples instead of pears because we are influenced by the advertisements displayed close to the apples on the supermarket's shelves.

Decreases in inhibition can also interact with age-related decreases in attention or memory. As we explained above, inhibition filters the information that is stored in (and retrieved from) memory. When the filter starts working less well, the wrong information may get selected, and people may also have difficulties rejecting information that was retrieved from memory wrongly.

INFERIOR FRONTAL GYRUS

A region of the prefrontal cortex that is involved in inhibition, language production, and empathetic response among other mechanisms.

WHY DOES INHIBITION BECOME LESS EFFICIENT?

Many researchers have examined the parts of the brain responsible for inhibition in young and older adults. As we already described, using fMRI, researchers have observed that the main part of the brain involved in inhibition is the prefrontal cortex, particularly a part of it called the **inferior frontal gyrus** (Figure 3) [4]. Researchers showed that

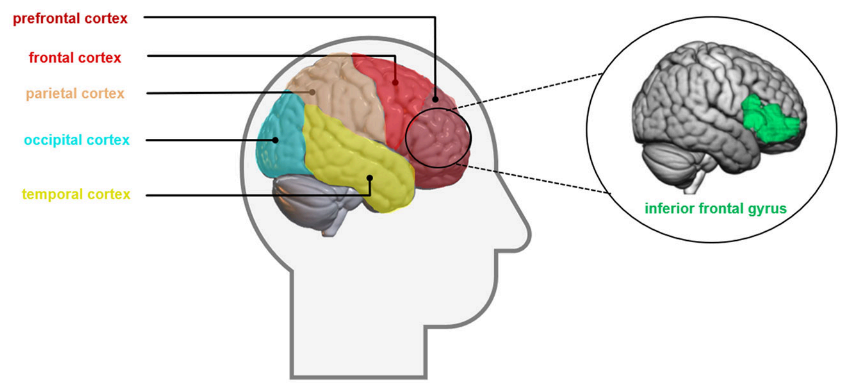

Figure 3

Figure 3

The prefrontal cortex, and specifically a part of it called the inferior frontal gyrus, is the part of the brain that supports inhibition. As people age, the prefrontal cortex gets smaller and a bit less efficient, which can negatively affect inhibition.

this part of the brain is often underactivated in older adults compared to younger ones, which means that the inferior frontal gyrus works less efficiently as people age. But why? Some studies showed that the prefrontal cortex gets smaller as we get older!

NOT ALL ASPECTS OF INHIBITION ARE IMPACTED BY AGING!

A recent study compared 11 inhibition tasks (quite similar to those presented in Figure 2) [5]. Using novel statistical methods, the researchers observed that the decline of inhibition is not the same across the various tasks or functions. For some tasks, there was no difference between the younger and older adults! Other scientists have shown that, even if the prefrontal cortex functions less efficiently in older adults, other brain parts may take the lead and compensate for the reduced efficiency of the prefrontal cortex! The good news is that aging is not an all-or-none process. It involves the recruitment of new brain strategies to cope with the effects of aging that affect some aspects of inhibition more than others.

In summary, inhibition is an essential but also complex ability. This ability shows very strong development during childhood, and then decreases slightly as we age. While the general concept of inhibition is well-studied, future studies are needed to understand the core cognitive and neural processes that define this concept.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

AKSHARA, AGE: 13
Science is everything, from the art of brushing to the way we interact with nature. All the information we learn is gathered in our brain. Our brain is not just a heavy load on our neck, it actually helps us to have fun, dream, and live. I am eager to know more about the mechanisms of how it functions. My aim is to understand how organisms interact with their environment to create a healthy society.

MAYA, AGE: 15
Maya has an analytical mind and a passion for science. She takes a measured, clearheaded approach to scientific questions and always looks for clarity and evidence in answers. She is particularly interested in the workings of the human mind and what makes people behave the way they do.

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I am a researcher at the University of Liège and the University of Tours. My goal is to better understand how we control and regulate ourselves. I am particularly interested in evaluating how these processes work as we age. In my free time, I enjoy cooking and having a hot Christmas chocolate at any time, while listening to pop-rock music and petting my two adorable cats. *coline.gregoire@uliege.be; coline.gregoire@univ-tours.fr; orcid.org/0000-0002-5907-1570

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